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LONG PATH OPTICAL EXTINCTION AND METEOROLOGY IN THE SAN FRANCISCO BAY AREA

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INTRODUCTION

As visibility studies in pristine areas progress in the next decade, many problems associated with visibility trend studies in cities will be rediscovered and amplified. Principle among these problems is separating the anthropogenic from the meteorological causes of changes in visibility. In cities one would expect the signal from anthropogenic visibility reducing pollution to dominate the meteorological noise. This is rarely the case. Though some attempts have been made to remove meteorological variation from seasonal visibility trends in cities (e.g., Klienman et al., 1976), it has never proved easy or terribly satisfactory over shorter periods. This is reflected in the high variability of visibility under similar source and measured meteorological conditions; due, at least in part, to the fact that visibility is a remotely sensed quantity and the meteorological variables have been taken from airport point measurements and rawinsondes. Our volunteer group at Chabot Observatory in Oakland, California has developed instrumentation and analysis techniques aimed at establishing the relationships between remotely sensed meteorological and visibility parameters of the atmosphere.

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In this paper, we will show first that long and short term visibility and atmospheric extinction trends are dominated by meteorological parameters. This is evident from 42 years of visibility data from Los Angeles as well as sparse nightly records of long path light extinction from stellar and artificial light sources over a three year period in the San Francisco Bay region. There is, however, considerable scatter in the relationship of regional scale atmospheric extinction and point meteorological data in the region. This is even more obvious in comparison of daytime and nighttime point light scattering measurements and the same meteorological parameters. These measurements do show, however, that light scattering in the Bay Area is usually significantly higher at night than during the day. This is true in spite of decreased emission and photochemical aerosol production. This fact again amplifies the dominant role of meteorological parameters on short and long term visibility trends.

Secondly, after describing the results of these past efforts, we will discuss new instrumentation and preliminary results using these instruments to remotely sense meteorological parameters along the same light path over which light extinction measurements are made. Those atmospheric parameters affecting visibility are water vapor, NO_2, ozone, aerosol, wind speed and stability or atmospheric temperature profile with height. All of these parameters can be remotely determined for a given light path by a combination of high resolution spectrographic absorption, low resolution wavelength extinction measurements optical scintillation and stellar refraction. Remotely sensed cross-path wind speeds are presently being determined from optical scintillation techniques and remote sensing of atmospheric mixing depths are being investigated using searchlight techniques or stellar refraction inversions.

EXPERIMENTAL FACILITY

Most of the results described in the following section were derived from our work as amateur astronomers in the East Bay Astronomical Society at Chabot Observatory in Oakland, California. This observatory contains 50 cm and 20 cm refracting telescopes which are used for stellar photometry and atmospheric refraction studies. We have also built a double 46 cm reflecting telescope system to be used in conjunction with a remote artificial light source (Porch et al., 1980). For our broad-band filter photometric studies, a 150 Watt-quartz iodine tungsten lamp was used with a dimpled reflector and chopped at 300 Hz. For spectrographic and remote wind sensing work, a 1000 Watt-tungsten lamp was used with a 50-cm Fresnel lens. In both cases, these light sources were placed on a remote controlled transmitter station on Mt. San Bruno 25 km across San Francisco Bay from the Observatory in Oakland. The elevations of the Observatory and the Mt. San Bruno light source are 107 m and 366 m, respectively. These elevations become important when inversion depth effects on atmospheric extinction are considered. We are fortunte that our light path is within several kilometers of the Oakland airport where two rawinsondes are launched daily and the San Francisco airport where daily observations are made.

At the receiving end of these telescopic systems are filters and photographic film for stellar photometry, filters and photomultipliers for low resolution telephotometry, servo-operated iris microphotometer, spectrograph and photomultipliers for high resolution spectrographic work, and photodiode arrays for remote wind sensing and optical turbulence studies. The photographs were painstakingly analyzed using a variable iris microphotometer (Galloway, 1975). Much of the early telephotometric data (1972-1974) was analyzed by hand from strip chart recordings. Presently, the analog data are digitized at rates varying from several seconds for the spectrographic data to 600 Hz for the photodiode array wind sensing system. These digital signals are then analyzed on a LSI 11/2 based distributed processing system.

RESULTS

This section is structured to show the dominant influence of meteorological parameters on urban atmospheric light extinction on progressively smaller temporal and spatial scales. The temporal scales vary from 42 years visibility trend analysis to nightly variability in long path integrated optical extinction. The spatial scales vary from regional scale atmospheric extinction and remotely sensed meteorology studies to point light scattering measurements with a nephelometer (Charlson et al., 1969) and airport rawinsonde data.

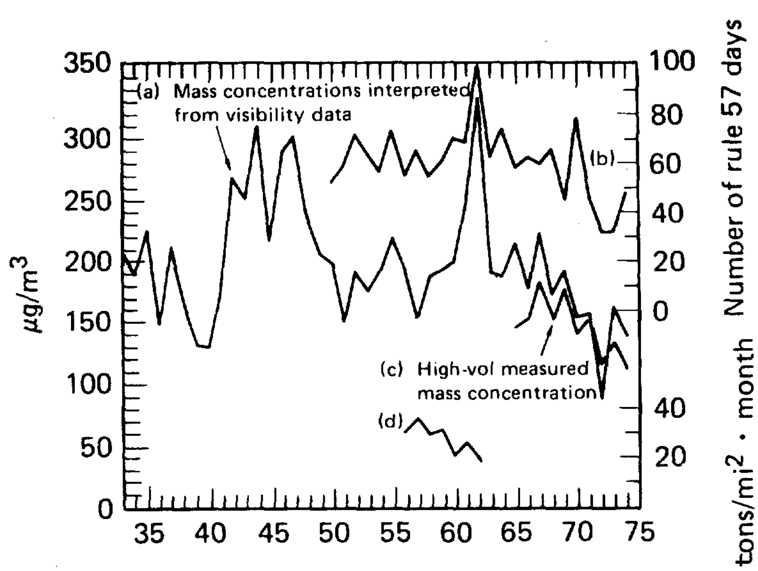

Figure 1. (a) Interpreted average mass concentrations from visibility data, (b) number of rule 57 days and (c) measured mass concentrations from June through November for available data periods between 1933 and 1974 in downtown Los Angeles between 1955 and 1962.

Figure 1 summarizes some earlier work we did studying long term visibility trends in Los Angeles. This figure shows over 40 years of summer and fall visibility data converted to mass concentrations by formulas derived from other work described in Porch and Ellsaesser (1977). These data and ten years of high volume filter aerosol mass collected over the same period show an obvious relation to the number of "rule 57 days" for the same period. A "rule 57 day" is defined as a day in which the morning inversion base height was less than 1500 ft, maximum mixing height was 3500 ft or less and the average 0600-1200 PST wind speed was 5 miles per hour or less. Some shorter term relationships between meteorological conditions and pollutant concentrations have been observed and used for urban areas (for example Holzworth (1972), Severs (1977) and DeMandel et al., (1980)).

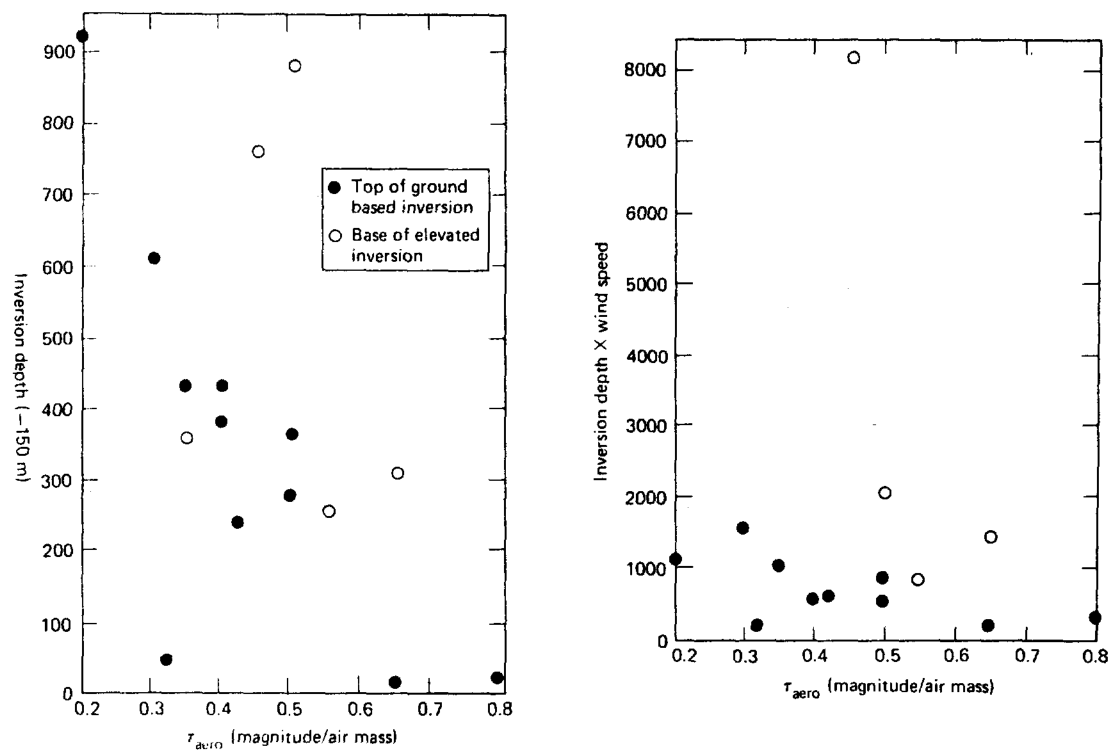

Figure 2. Aerosol component of stellar photometry derived optical depth versus inversion depth (less 150 m) and inversion depth times wind speed (m^2/sec) measured above Oakland Airport.

Below, we show our results interconnecting nighttime long path optical extinction in the Bay Area and short term meteorological parameter changes measured at and above Oakland Airport. Beginning in 1972, two types of telephotometric studies were begun at Chabot Observatory. The first involved photographic analysis of ten-color filter spectral extinction of the star cluster Pleiades. A star cluster was chosen rather than a single star to calibrate individual photographic film response. Figure 2 shows the results of comparing the aerosol contribution to optical extinction in stellar magnitudes per air mass at 500 nm (τ_{aero}) with inversion depths and inversion depths multiplied by surface wind speeds measured at 04:00 PST. Figure 3 shows τ_{aero} plotted against wind speed and humidity values at reported heights nearest the Observatory. Some relationship is evident in these figures between τ_{aero} and the meteorological parameters (especially wind speed and inversion depth). However, since τ_{aero} is the aerosol extinction coefficient (b_{ext}) multiplied by the aerosol scale height (H_{aero}) the effect of inversion depth is complicated by the fact that H_{aero} would increase with inversion depth while b_{ext} would decrease. For this reason, a second type of telephometric study was begun which used a 25 km horizontal path and a remote artificial light source who's intensity was calibrated photometrically (and by using setting standard stars with a model atmosphere).

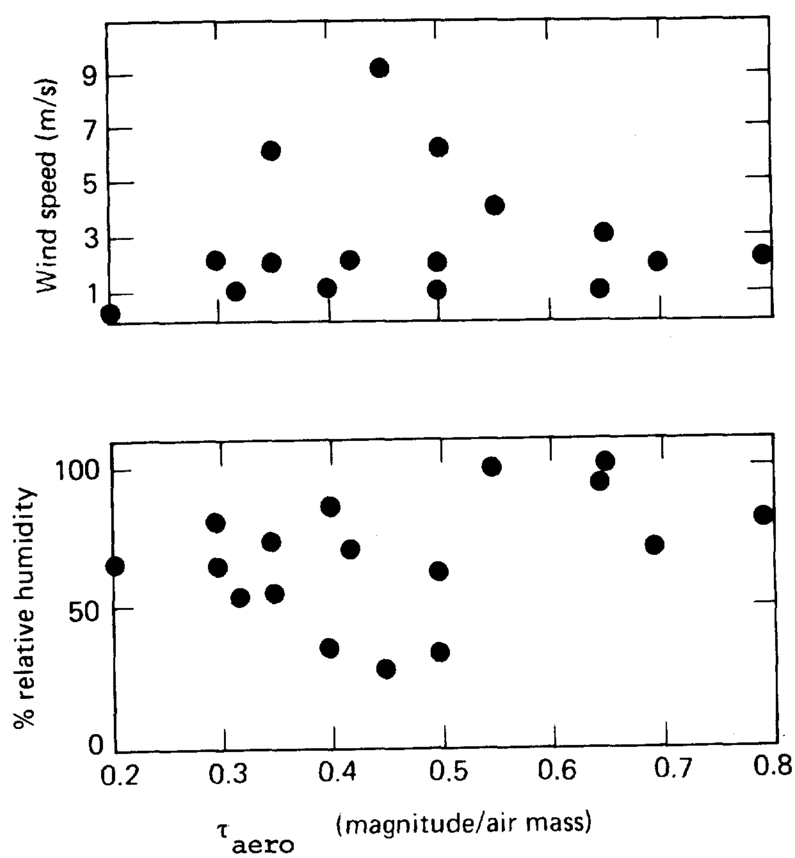

Figure 3. Aerosol component of stellar photometry derived optical depth versus wind speed and percent relative humidity from Oakland sounding at height closest to Observatory.

Figures 4 and 5 show the results using this artificial light technique analogous to the stellar photometry shown in Figures 2 and 3. In this case, the relationship of inversion depth and atmospheric extinction coefficient (b_{ext}) is more clear. When the inversion depth is less than the of the horizontal light path height the relationship obviously breaks down. The relation between long path (25 km) extinction and point measured wind speeds and humidity are still quite scattered. Even greater scatter between these variables is seen when point nephelometer measurements taken at the observatory are compared with meteorological parameters measured at the Oakland Airport surface.

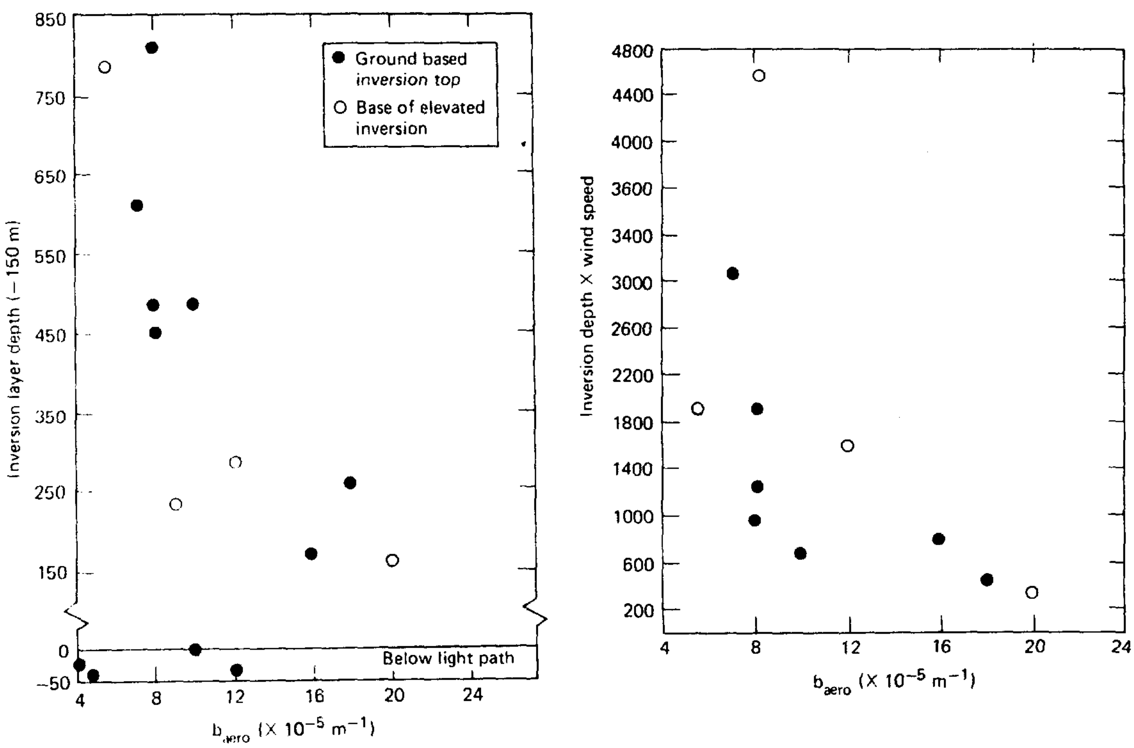

Figure 4. Aerosol extinction coefficient derived from a 25 km distant artificial light source versus the same functions of inversion depth shown in Figure 3.

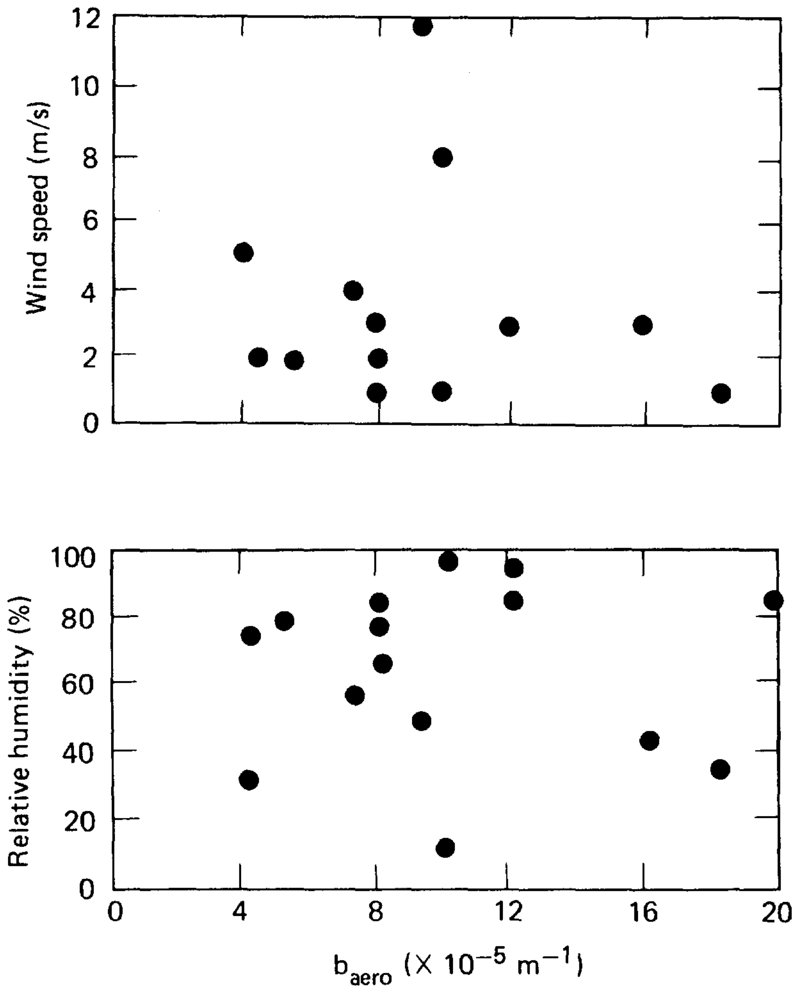

Figure 5. Aerosol extinction coefficient versus wind speed and percent relative humidity from Oakland sounding at height closest to light path.

Figure 6 shows the ratio of the light scattering coefficient (b_{scat}) measured at 04:00 PST to that measured at 16:00 PST versus the ratio of the meteorological parameters. In this figure a distinction is made between summer and winter measurements. Almost all the data plotted in Figures 2-5 were winter and spring measurements. It is obvious in Figure 6 that during the summer (June-October) inversion depth is typically higher at night than during the day due to land-sea and mountain valley breezes (Lorenzen, 1979). In any case, Figure 6 shows that most of the year light scattering is higher at night than during the day ($\sim$79% of the time) in spite of reduced aerosol sources (both direct and photochemical) at night. Obviously, this is a meteorological phenomena. Figure 6 shows the facts that inversion depths are usually lower at night, that relative humidity is higher, and wind speeds are usually lower; all contributing to this effect.

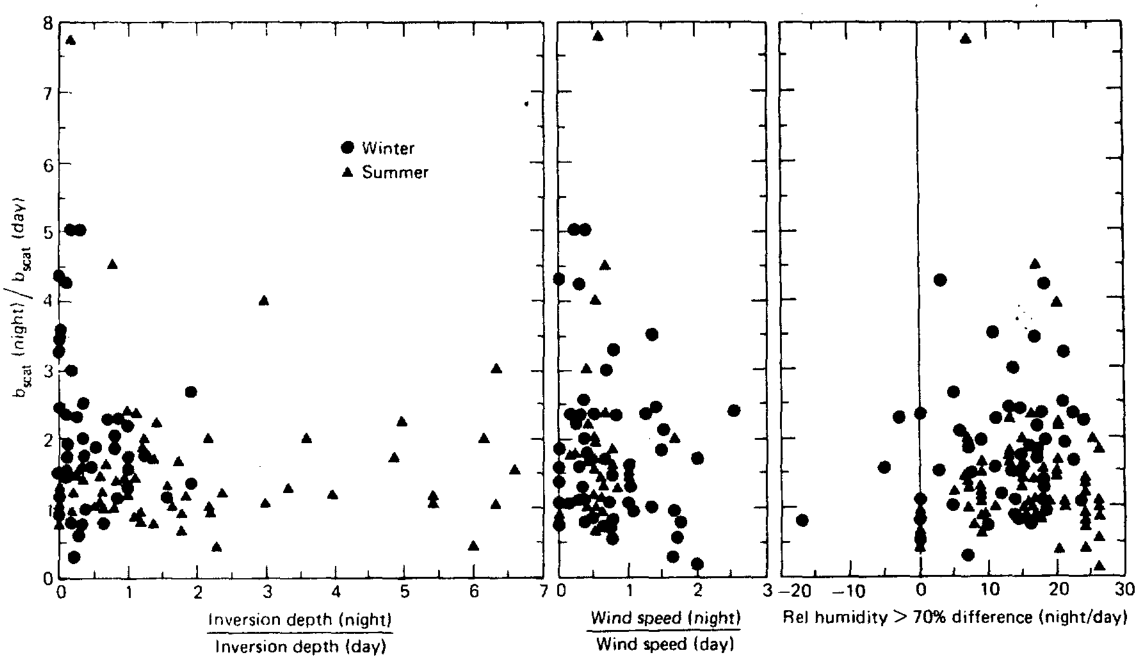

Figure 6. The ratio of 1 hour averaged nephelometer derived light scatter coefficients at 04:00 and 16:00 PST versus the ratios of inversion depths and wind speeds for the same periods and differences in relative humidities greater than 70%. These data were distinguished by summer (June-October) and winter (November-May) designations.

Other differences between daytime and nighttime aerosol characteristics have been observed when our data are compared to turbidity studies in the region (e.g., Russell et al., 1979). Turbidity studies in urban areas almost invariably show a regular decrease in aerosol caused light extinction with increasing wavelength. Many measurements in background locations especially at night, over long paths show the opposite behavior in the 500-600 nm region of the spectrum (Porch et al., 1973). Figure 7 shows this kind of behavior at Chabot Observatory from our stellar extinction studies. Similar behavior was observed in our artificial light source extinction measurements. Chappuis ozone absorption would require an ozone column over double the normal 325 milli-atm-cm to explain the effect shown in Figure 7. The more likely cause of this effect is the tendency of aerosol to form in atmospheric layers which at night (with no photochemical small particle production) coalesce into a fairly monodisperse size distribution centered around 0.5 μm radius. Humidity effects may also contribute to this particle growth effect.

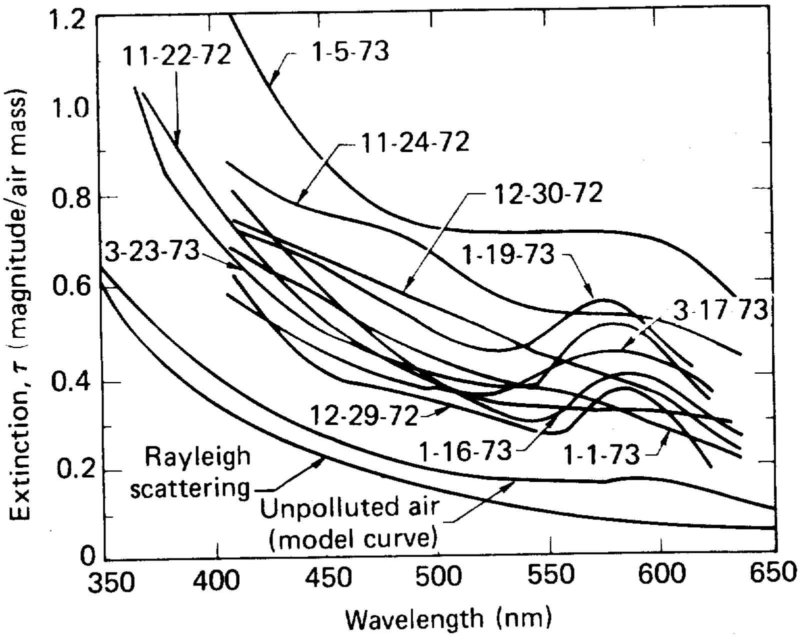

Figure 7. Spectral extinction coefficients of stellar data (uncorrected for ozone and NO_2 absorption) showing commonly observed red hump between 500 and 600 nm.

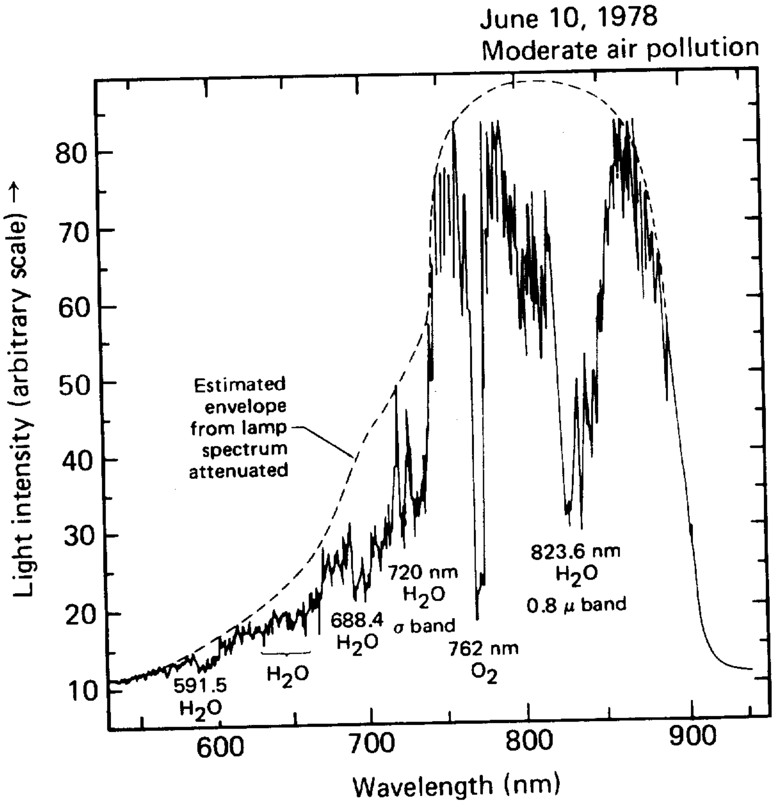

Figure 8. Photoelectrically determined spectrum (near infrared) for 25 km path across San Francisco Bay at a height of between 100 and 300 m.

Our efforts at Chabot Observatory over the past three years have been focused on the development and testing of instrumentation to sense remotely meteorological parameters over the same light path that atmospheric extinction is measured. Preliminary data have been obtained which show the ability of our instrumentation to sense remotely atmospheric water vapor and cross-path wind speeds. Figure 8 shows high resolution spectra taken over the 25 km path across San Francisco Bay. Water vapor line absorptions are obvious and will be used for remote humidity sensing. Besides water vapor effects, photographic analysis of stellar spectra show NO_2 and O_2 absorption features. A new light source is being constructed to allow remote sensing of NO_2 and ozone with photoelectric techniques.

Figure 9 illustrates how optical turbulence can be used to derive long-path cross winds. This technique has been developed over the last ten years (Ochs et al., 1976). The light source (usually 15 cm or more in diameter to avoid scintillation saturation) is observed by two horizontal tangent detectors. Figure 9 shows examples of two correlation functions between the two detectors for high and low wind speed cases (5.5 and 1 m/s respectively). Various features of this correlation function can be used to determine the wind speed such as 1) the slope at zero time lag (basis of most analog systems), 2) the peak time delay to maximum correlation, or 3) spectral peak of spatially filtered signal. In our application, rather than use two separate detectors the light is imaged through a cylindrical lens on a photodiode array and the two halves compared. Winds determined by this technique were found to compare well with winds measured at the Oakland Airport (Porch et al., 1980).

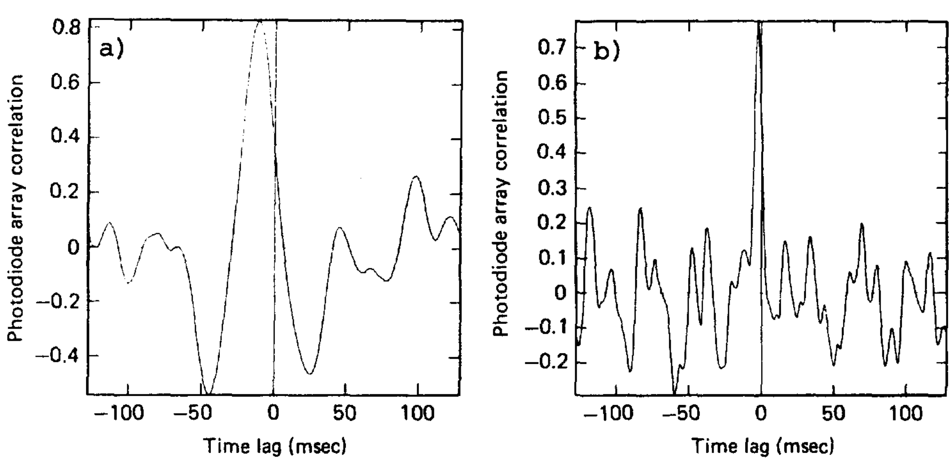

Figure 9. Plots of the correlation function for relatively low (1 m/s) a) and high (5.5 m/s), b) north winds using two halves of a photodiode array.

Our future plans include calibrating the remote sensing techniques and testing them with diverse meteorological conditions over as many data periods as possible. Secondly, we hope to develop remote sensing capabilities for sensing mixing depths using stellar refraction (Fraser, 1977) and searchlight techniques. This would allow more than a once nightly comparison with the Oakland rawinsonde.

CONCLUSIONS

Our work has shown the following:

1. Long term urban visibility trends are dominated by meteorological variability.

2. Short term relationships between atmospheric light extinction and meteorological parameters are also apparent (especially temperature inversion depth).

3. Aerosol light scattering is greater and colored differently at night than during the day in the Bay Area.

New developments in remote sensing techniques show promise in improving our understanding of the relation of important meteorological parameters and atmospheric light extinction. This is especially important to pristine area visibility studies where long term comparisons with airport rawinsondes will be impossible.

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